



Highlighting the F2 trace on an ionogram to improve Autoscala performance

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ABSTRACT

This work describes a linear regression based method for highlighting the cuspidal trace on an ionogram. This method was initially thought to smooth out cases in which the autoscaling of the ionogram performed by Autoscala was erroneous because the F2 ordinary ray was identified as the extraordinary ray. The development of this method is very useful for filtering out noise and assisting the main algorithm of Autoscala to not be misled by multiple-hop sporadic E layer echoes. Applying the algorithm to different ionograms recorded by different ionosondes showed that the application of this method considerably improved the Autoscala performance. The role that this method plays in the light of existing algorithms is also discussed.

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1. Introduction

In the last three decades much work has been devoted to developing computer programs able to automatically scale vertical incidence ionograms: the Automatic Real-Time Ionogram Scaling with True-height (ARTIST) system (Reinisch and Huang, 1983; Galkin and Reinisch, 2008), is based on a hyperbolic trace fitting method and uses information on wave polarization; Fox and Blundell (1989) designed a system, relying on an ionosonde only able to record the ordinary ray echoes, by which a trace is formed using successive mathematical extrapolations; the algorithm developed by Igi et al. (1993) does not distinguish between ordinary and extraordinary mode components and it is based on parabolic and hyperbolic curve fitting; Tsai and Berkey (2000) developed a method based on the concepts of fuzzy segmentation and connectedness; an iterative ray-tracing approach is used by Zabolotn et al. (2006) to perform a three-dimensional electron density profile inversion for dynasonde ionograms; Ding et al. (2007) presented a method based on empirical orthogonal functions in combination with an image matching technique to automatically scale only the F2 layer parameters.

Scotto and Pezzopane (2002) designed a program, called Autoscala, based on an image recognition technique that can run without polarization information. The fact that it is based on an image recognition technique allows the algorithm to be not strictly related to the hardware features of a particular ionosonde, and the capacity to work also without having information on the

polarization allows it to be applied to any kind of ionosonde. Once the ionogram is loaded as a matrix, the first stage adopted in autoscaling it is to run an F2 routine to identify the F2 ionogram trace by defining two empirical curves T_1 and T_2 that are able to fit the typical shape of the F2 trace (Pezzopane and Scotto, 2007). This first stage is very important because using two curves instead of only one, such as what is done in the work of Fox and Blundell (1989), Reinisch and Huang (1983), Tsai and Berkey (2000), and Zabolotn et al. (2006), is the strong point that provides Autoscala with the possibility to be applied to ionograms recorded by old fashioned ionosondes in which the ordinary and extraordinary modes are recorded together and tagged in an undistinguished way. The second stage is to use the information retrieved in the first stage to perform the autoscaling of the F1 ionogram trace (Pezzopane and Scotto, 2008). This means that the first stage is an important step in the algorithm logic. If performed incorrectly, layer identifications and scaled parameters may often be incorrect.

After a few years of applying Autoscala to ionograms recorded at Rome (Italy, 41.8°N, 12.5°E) and Gibilmanna (Italy, 37.9°N, 14.0°E) ionospheric stations by the AIS-INGV ionosonde (Zuccheretti et al., 2003), and after a few tests performed on ionograms recorded at Tucumán (Argentina, 26.9°S, 294.6°E) by the AIS-INGV ionosonde (Pezzopane et al., 2007) and at Moscow (Russia, 55.5°N, 37.3°E) by the AIS-Parus ionosonde (Krasheninnikov et al., 2010), the authors noted a systematic error committed by the Autoscala program. This occurs mostly for daytime ionograms, when it is most likely to happen that the ordinary ray of the F2 ionogram trace is more defined than the extraordinary ray (which in these cases is almost or totally absent), and also for ionogram traces where the parameter $h'F$ (absence of F1 layer) or $h'F2$

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(presence of F1 layer) (Wakai et al., 1987) is well defined. In this case Autoscala may in fact identify the ordinary ray as the extraordinary ray with a consequent underestimation of the f_oF2 and $MUF(3000)F2$ (and of course $M(3000)F2$) values given automatically as output (Fig. 1b).

This incorrect scaling occurs when the weakness of the extraordinary trace causes the failure of the technique based on maximum correlation used by the kernel of Autoscala. In this technique the information gained from both the ordinary and extraordinary traces is taken into account and only the points characterized by a high value of the derivative are considered (Pezzopane and Scotto, 2007).

This work describes a method to mitigate this problem and, therefore, make the Autoscala output more reliable. In addition this paper will show how this method turned out to also be very useful for filtering out noise and assisting the main algorithm of Autoscala to not be misled by multiple-hop sporadic E (Es) layer echoes.

2. Highlighting the F2 trace on an ionogram

The basic idea of the method is to create from an original recorded ionogram another ionogram in which the typical vertical asymptotical shape of the F2 trace is enhanced while the parts of the trace characterized by a horizontal or quasi-horizontal behaviour and by behaviour exhibiting negative slope, that

contributes to misleading Autoscala, are deleted (see Fig. 1). This new ionogram is processed only by the F2 routine, the F1 and Es routines (Pezzopane and Scotto, 2008; Scotto and Pezzopane, 2007) process the original ionogram.

To achieve this, initially the ionogram is loaded by Autoscala as a matrix A of n columns and m rows whose numbers are defined by the following formulas:

$$n = \text{int}[(f_f - f_0)/\Delta f] + 1, \quad (1a)$$

and

$$m = \text{int}[(hf' - h_0)/\Delta h'] + 1, \quad (1b)$$

where f_f , h_f' , f_0 , h_0 , and Δf are, respectively, the final frequency, the final virtual height, the initial frequency, the initial virtual height, and the frequency step of the sounding; $\Delta h'$ is the height resolution at which the sounding has been recorded. The element a_{xy} (with $x=1, \dots, m$ and $y=1, \dots, n$) of the matrix A is an integer, the higher the value, the stronger the echo amplitude received by the ionosonde.

Next, a matrix A' is defined with dimensions the same as matrix A and with all entries a'_{xy} equal to zero.

The method developed considers a rectangle, whose sides d_f in frequency and d_h in height are 0.3 MHz and 36 km, inside which the ionogram can be approximated to a straight line. The rectangle is slid on the ionogram by varying the frequency and the virtual height of its centre from $(f_0 + d_f/2)$ to $(f_f - d_f/2)$ and from $(h_0 + d_h/2)$ to $(h_f - d_h/2)$, respectively.

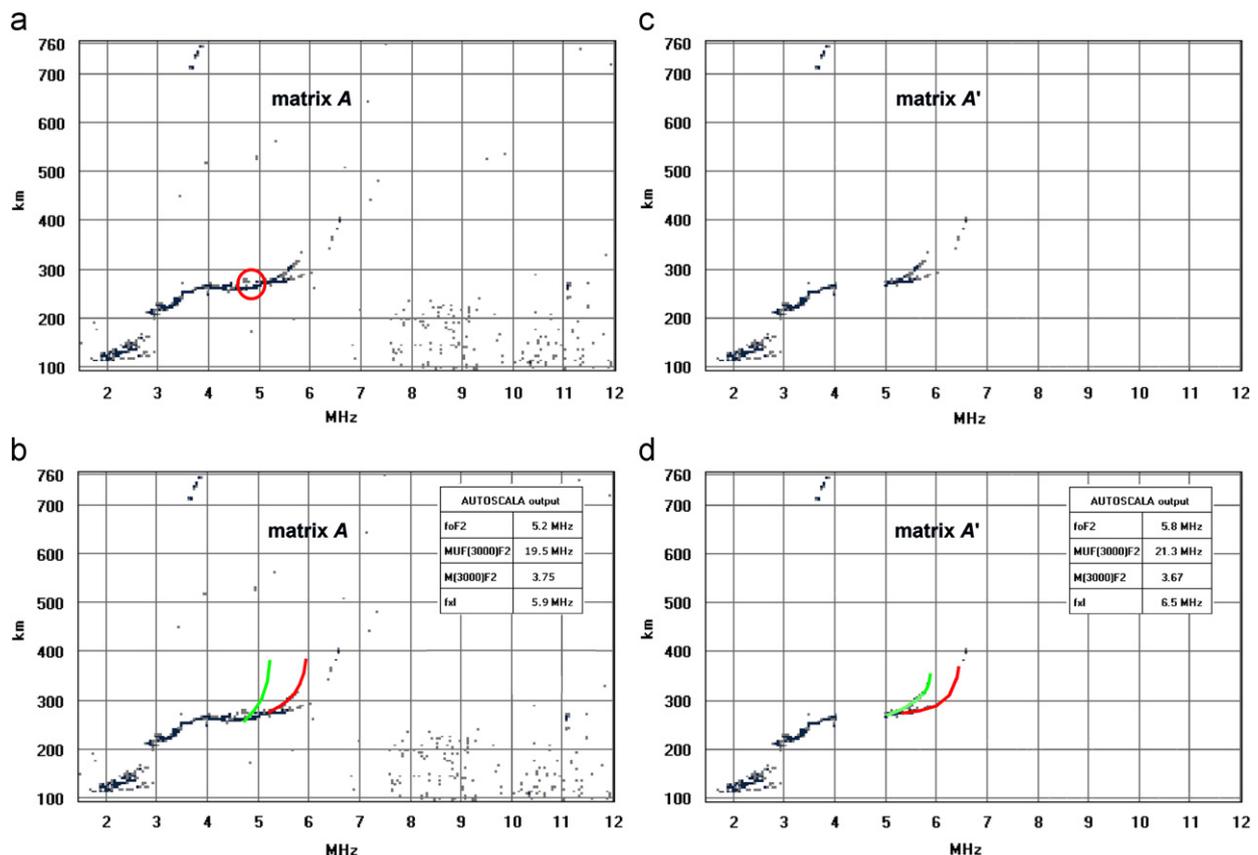


Fig. 1. (a) Ionogram recorded on 1 March 2005 at 08:15 UT by the AIS-INGV installed at Rome. Red open circle highlights part of ionogram trace, characterized by a horizontal or quasi-horizontal behaviour, that contributes to misleading Autoscala. (b) Autoscaling performed by F2 routine of Autoscala (in green and in red, ordinary and extraordinary traces, respectively, identified by software) which incorrectly identifies ordinary ray as extraordinary ray, considering ionogram points contained in red circle. (c) Ionogram loaded in matrix A' , in which parts of trace characterized by a horizontal or quasi-horizontal behaviour and by a behaviour with negative slope have been deleted, and which is subsequently processed by F2 routine. (d) Correct autoscaling performed by F2 routine of Autoscala on ionogram loaded in matrix A' . (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

If inside the rectangle a number $N \geq 3$ of points whose echo amplitude is different from zero is found the following m and b (gradient and intercept of the regression line) are computed:

$$m = \frac{\left(\sum_{i=1}^N p_i\right) \left(\sum_{i=1}^N x_i y_i p_i\right) - \left(\sum_{i=1}^N y_i p_i\right) \left(\sum_{i=1}^N x_i p_i\right)}{\left(\sum_{i=1}^N p_i\right) \left(\sum_{i=1}^N x_i^2 p_i\right) - \left(\sum_{i=1}^N x_i p_i\right)^2}, \tag{2a}$$

$$b = \frac{\left(\sum_{i=1}^N x_i^2 p_i\right) \left(\sum_{i=1}^N y_i p_i\right) - \left(\sum_{i=1}^N x_i y_i p_i\right) \left(\sum_{i=1}^N x_i p_i\right)}{\left(\sum_{i=1}^N p_i\right) \left(\sum_{i=1}^N x_i^2 p_i\right) - \left(\sum_{i=1}^N x_i p_i\right)^2}, \tag{2b}$$

where p_i (corresponding to the value of the element of the matrix A) is considered as the weight associated with the ionogram point whose matrix indices are x_i and y_i .

The choice of linear regression was suggested by the fact that this method is useful also for filtering out noise, which has on the ionogram a typical vertical line signature, and for assisting the main algorithm of Autoscala to not be misled by multiple-hop Es layer echoes, typically represented by horizontal line signatures. Concerning the values chosen for d_f and d_h , the authors have performed some tests with corresponding different values and they have found that 0.3 MHz and 36 km are the best ones; the larger the values, the less the ability to approximate the ionogram to a straight line, the smaller the values, the smaller is the enhancement of the asymptotical shape of the F2 trace.

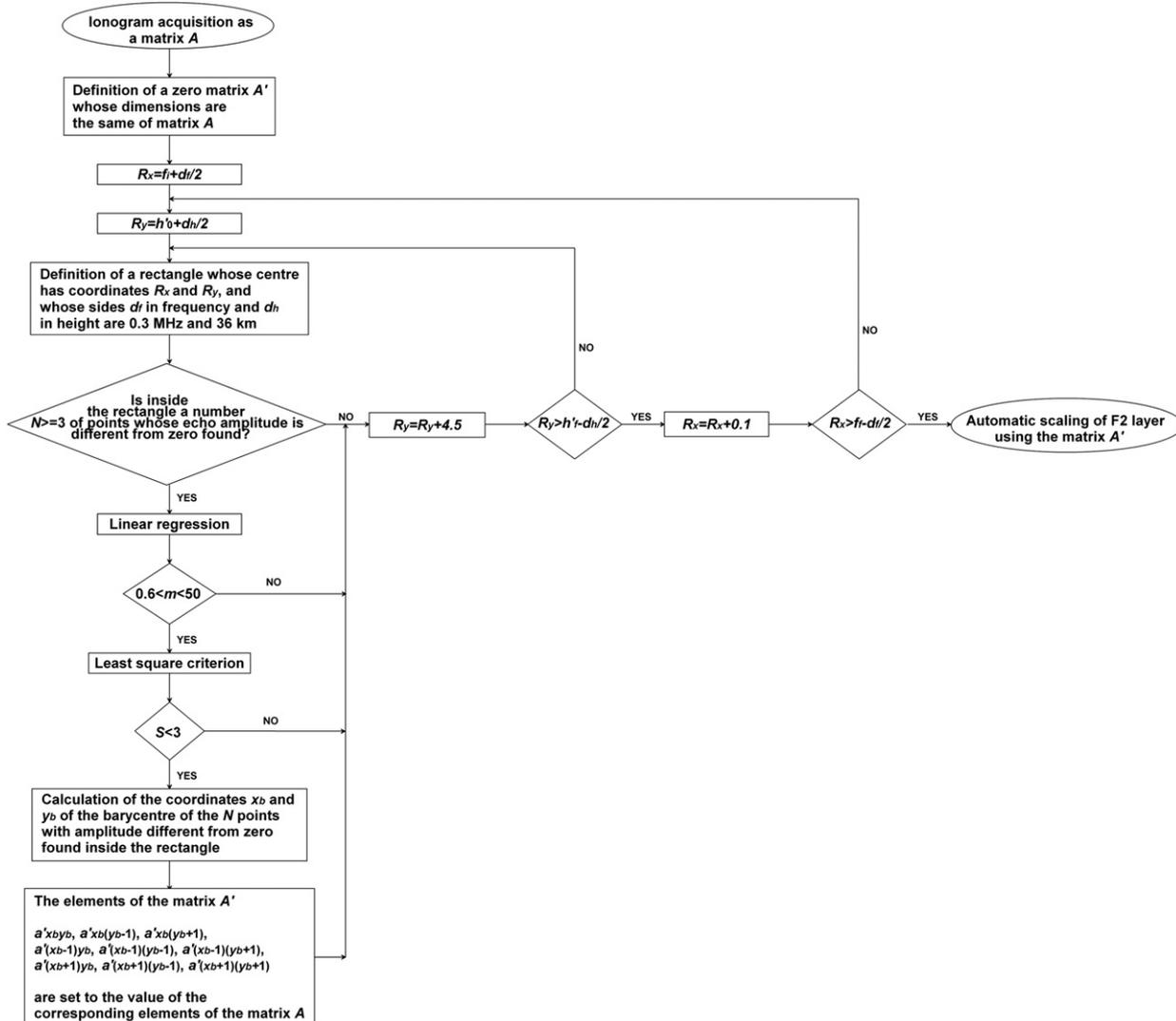


Fig. 2. Flowchart of algorithm described in this paper to highlight F2 trace on an ionogram.

Table 1

Performance of F2 layer identification routine before and after applying method for highlighting F2 trace on ionograms recorded at Rome ionospheric station.

	Correctly scaled	Incorrectly scaled (subset 1)	Incorrectly scaled (subset 2)	Not scaled
Before applying the method	8973	98	19	
After applying the method	8988	18	15	69

If $0.6 < m < 50$ in order to define whether the regression line best fits the ionogram trace, the squared residual $r_i^2 = (mx_i + b - y_i)^2$ is multiplied by p_i and the following least squares criterion is used:

$$S = \frac{\sum_{i=1}^N r_i^2 p_i}{\sum_{i=1}^N p_i} \quad (3)$$

If $S < 3$ (it was found that this limit along with the ones characterizing m are sufficient to consider horizontal and vertical signatures as not belonging to the ionogram trace) the coordinates x_c and y_c of the central point within the set of the N points with amplitude different from zero found inside the rectangle are

calculated as follows:

$$x_c = \text{int} \left[\frac{\sum_{i=1}^N x_i p_i}{\sum_{i=1}^N p_i} \right], \quad (4a)$$

$$y_c = \text{int} \left[\frac{\sum_{i=1}^N y_i p_i}{\sum_{i=1}^N p_i} \right]. \quad (4b)$$

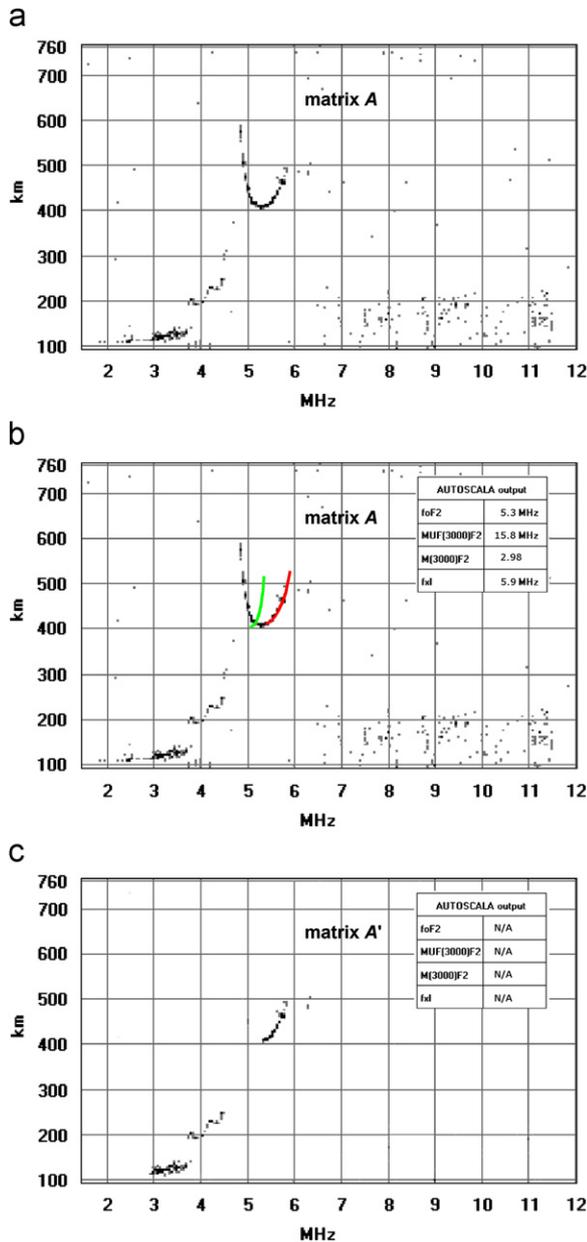


Fig. 3. (a) Ionogram recorded on 2 June 2005 at 11:45 UT by AIS-INGV installed at Rome. (b) Autoscaling performed by F2 routine of Autoscala (in green and in red, ordinary and extraordinary traces, respectively, identified by software) which incorrectly identifies ordinary ray as extraordinary ray. (c) Ionogram loaded in matrix A', in which parts of trace having a horizontal or quasi-horizontal behaviour and a behaviour with negative slope have been deleted. This ionogram was not scaled by F2 routine of Autoscala since it was assessed as providing insufficient information. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

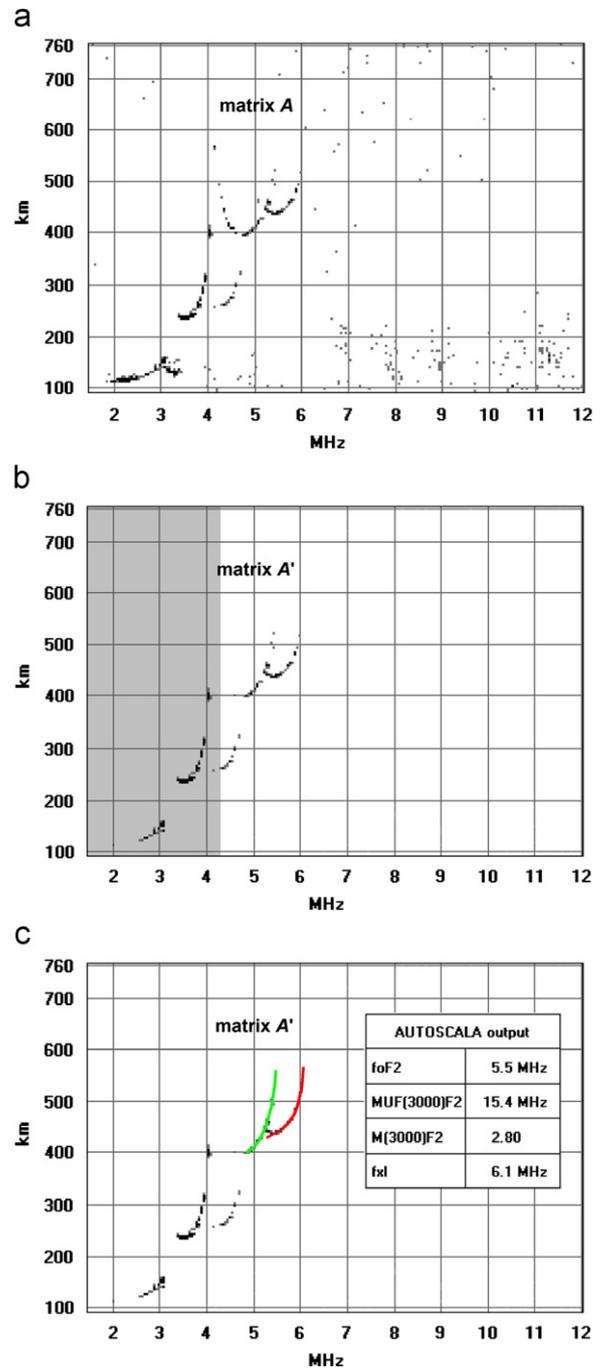


Fig. 4. (a) Ionogram recorded on 7 June 2005 at 07:45 UT by the AIS-INGV installed at Rome. (b) Ionogram loaded in matrix A', in which parts of trace characterized by a horizontal or quasi-horizontal behaviour and by a behaviour with negative slope have been deleted, and which is subsequently processed by F2 routine. Grey area indicates ionogram sector where F2 routine is not applied. (c) Correct autoscaling performed by F2 routine of Autoscala on ionogram loaded in matrix A'. In green and in red, ordinary and extraordinary traces, respectively, identified by software. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

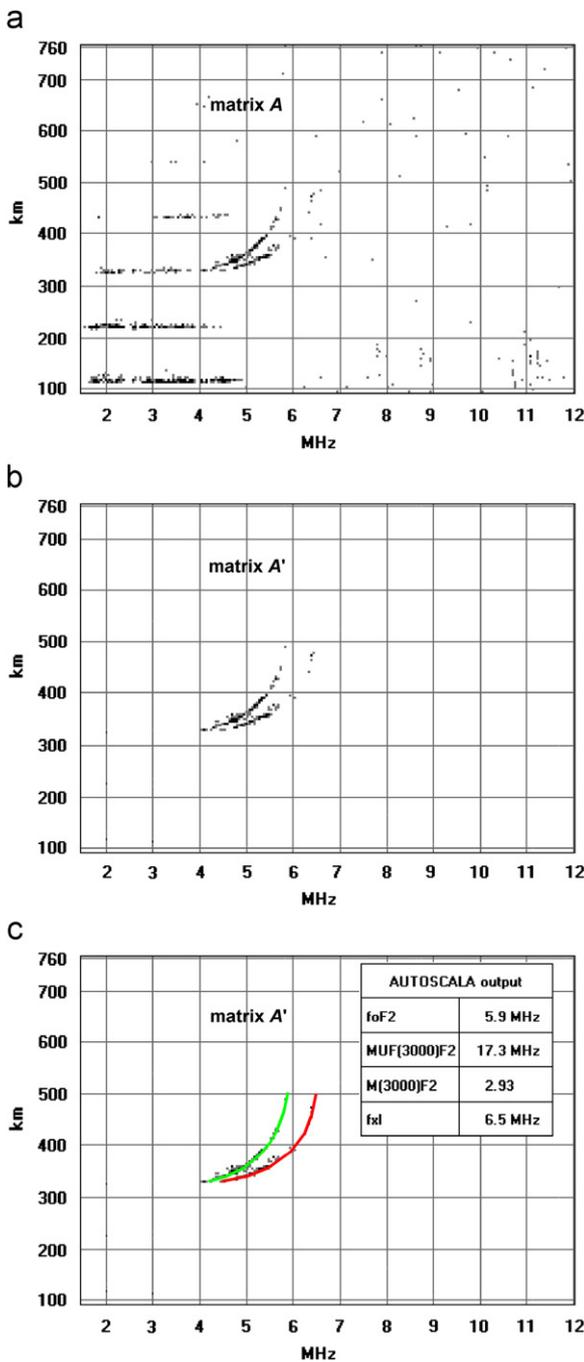


Fig. 5. (a) Ionogram recorded on 3 June 2005 at 21:45 UT by the AIS-INGV installed at Rome. (b) Ionogram loaded in matrix A' , in which parts of trace characterized by a horizontal or quasi-horizontal behaviour and by a behaviour with negative slope have been deleted, and which is subsequently processed by F2 routine. (c) Correct autoscaling performed by F2 routine of Autoscala on ionogram loaded in matrix A' . In green and in red, ordinary and extraordinary traces, respectively, identified by software. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The following elements of the matrix A'

$$a'_{x_c y_c}, a'_{(x_c)(y_c-1)}, a'_{(x_c)(y_c+1)}, a'_{(x_c-1)y_c}, a'_{(x_c-1)(y_c-1)}, a'_{(x_c-1)(y_c+1)}, a'_{(x_c+1)y_c}, a'_{(x_c+1)(y_c-1)}, a'_{(x_c+1)(y_c+1)} \quad (5)$$

are then set to the value of the corresponding elements of the matrix A :

$$\begin{aligned} a'_{x_c y_c} &= a_{x_c y_c}, \\ a'_{(x_c)(y_c-1)} &= a_{(x_c)(y_c-1)}, \\ a'_{(x_c)(y_c+1)} &= a_{(x_c)(y_c+1)}, \\ a'_{(x_c-1)y_c} &= a_{(x_c-1)y_c}, \\ a'_{(x_c-1)(y_c-1)} &= a_{(x_c-1)(y_c-1)}, \\ a'_{(x_c-1)(y_c+1)} &= a_{(x_c-1)(y_c+1)}, \\ a'_{(x_c+1)y_c} &= a_{(x_c+1)y_c}, \\ a'_{(x_c+1)(y_c-1)} &= a_{(x_c+1)(y_c-1)}, \\ a'_{(x_c+1)(y_c+1)} &= a_{(x_c+1)(y_c+1)}. \end{aligned} \quad (6)$$

After sliding the rectangle across the entire ionogram the matrix A' represents the real matrix that will be processed by the F2 routine. Fig. 2 illustrates the flowchart of the algorithm described in this paper.

3. Performance of the method

In total 11,207 ionograms recorded in the equinoctial and solstitial months of 2005 by the AIS ionosonde installed at Rome were first processed by Autoscala without the addition of the routine for highlighting the F2 trace. Once processed only the 9090 ionograms for which Autoscala gave a numerical value for the F2 layer parameters were considered and these were processed again but this time using Autoscala with the routine for highlighting the F2 trace. Table 1 presents the results of the analysis. The ionograms were divided into those correctly and incorrectly scaled by the software, and the incorrectly scaled ionograms in turn were split into two groups: one group (subset 1) containing the ionograms wrongly scaled by Autoscala because the ordinary ray was identified as the extraordinary ray, as explained in the Introduction, and a second group (subset 2) containing the ionograms wrongly scaled by Autoscala for other reasons (for instance, presence of spread F condition).

It emerged that after applying the routine for highlighting the F2 trace the number of ionograms belonging to subset 1 of incorrectly scaled ionograms diminished, without affecting the number of ionograms correctly scaled. In the majority of cases, ionograms previously incorrectly scaled were not scaled by Autoscala because they were assessed as providing insufficient information (Pezzopane and Scotto, 2007) (Fig. 3). In these cases no values were given as output reducing the production of wrong data. In addition, this method also helped Autoscala to correctly scale some ionograms previously not successfully scaled (Fig. 1d).

Table 2
Performance of F2 layer identification routine before and after applying method for highlighting F2 trace on ionograms recorded at Gibilmanna ionospheric station.

	Correctly scaled	Incorrectly scaled (subset 1)	Incorrectly scaled (subset 2)	Not scaled
Before applying the method	3187	45	17	
After applying the method	3199	18	13	19

4. Special ionogram cases

This section goes into more detail, devoting attention to two special ionogram cases, characterizing the analysis described in Section 3, and discussing how Autoscala deals with the ionograms after highlighting the F2 trace.

4.1. Ionograms showing the F1 and F2 layers

The method described in this paper was designed essentially for the F2 layer trace but its application will highlight all the parts

of an ionogram characterized by a positive slope, with $0.6 < m < 50$, of the straight line to which the ionogram is approximated inside the rectangle that is slid all over the ionogram. This means that, after applying the method to ionograms showing both an F1 layer and an F2 layer, the F2 routine starts processing a resulting ionogram like the one shown in Fig. 4b. In this case both the trace near the vertical asymptotical behaviour of the F2 layer and the trace, with a positive slope, near the vertical asymptotical behaviour of the F1 layer are highlighted. Autoscala however is not misled because the identification of the F2 layer trace as the F1 layer is avoided by

Table 3

Performance of F2 layer identification routine before and after applying method for highlighting F2 trace on ionograms recorded at Moscow ionospheric station.

	Correctly scaled	Incorrectly scaled (subset 1)	Incorrectly scaled (subset 2)	Not scaled
Before applying the method	2723	34	21	
After applying the method	2738	14	13	13

Table 4

Performance of F2 layer identification routine before and after applying method for highlighting F2 trace on ionograms recorded at Tucumán ionospheric station.

	Correctly scaled	Incorrectly scaled (subset 1)	Incorrectly scaled (subset 2)	Not scaled
Before applying the method	2096	32	17	
After applying the method	2118	11	9	7

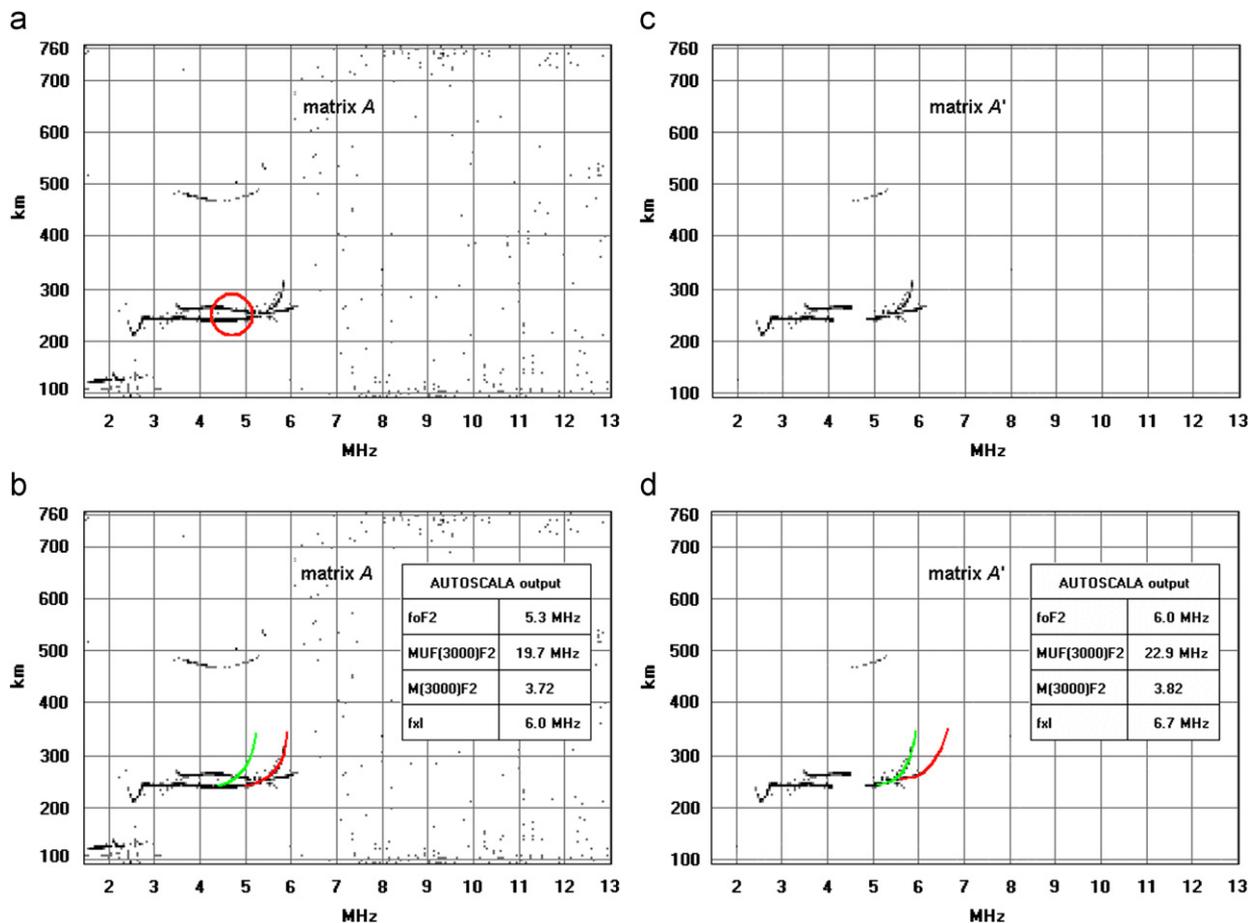


Fig. 6. (a) Ionogram recorded on 9 January 2007 at 07:45 UT by AIS-INGV installed at Gibilmanna. Red open circle highlights part of ionogram trace, characterized by a horizontal or quasi-horizontal behaviour, that contributes to misleading Autoscala. (b) Autoscaling performed by F2 routine of Autoscala (in green and in red, ordinary and extraordinary traces, respectively, identified by software) which incorrectly identifies ordinary ray as extraordinary ray, considering ionogram points contained in red circle. (c) Ionogram loaded in matrix A', in which parts of trace characterized by a horizontal or quasi-horizontal behaviour and by a behaviour with negative slope have been deleted, and which is subsequently processed by F2 routine. (d) Correct autoscaling performed by F2 routine of Autoscala on ionogram loaded in matrix A'. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

calculating the monthly median value of $foF1$ using the DuCharme et al. (1973) model and not applying the F2 routine to curves having an asymptote a_{ord} smaller or too close to this value (grey sector in Fig. 4b) (Pezzopane and Scotto, 2007).

4.2. Ionograms showing multiple Es layers

When multiple Es layers are present on an ionogram, autoscaling methods may be misled. In fact a multiple trace from a strong Es layer (typically the second order echo reflected from the Es layer) can be confused with the F layer trace, leading to the critical frequency of the Es layer being scaled as $foF2$ (see for instance Fig. 6 of Pezzopane and Scotto (2007)).

Autoscala is designed to recognize the typical vertical asymptotical behaviour of the F2 traces, and usually it is not confused by the presence of multiple Es layers.

Applying the method described in this work, Autoscala definitively avoids being puzzled by these kinds of ionograms because the ionogram matrix A' processed by the F2 routine is without Es traces, as shown in Fig. 5.

5. Application of the method to ionograms recorded in other stations, and by other ionosondes

In order to prove that the algorithm parameters are optimally selected, and that the algorithm will work on datasets outside the control set of Rome ionograms, the analysis described in Section 3 was performed also for 3249 ionograms recorded at Gibilmanna in 2007 by the AIS-INGV ionosonde, 2778 ionograms recorded at Moscow in 2009 by the AIS-Parus ionosonde, 2145 ionograms recorded at Tucumán in 2008 by the AIS-INGV ionosonde, and 2965 ionograms recorded at Warsaw (Poland, 52.2°N, 21.1°E) in 2009 by the VISRC2 ionosonde (Pezzopane et al., 2008).

The results of the analysis presented in Tables 2–4 for Gibilmanna, Moscow, and Tucumán are very similar to those shown in Table 1, suggesting that the developed method is independent of both the site and the type of the ionosonde. Figs. 6–8 show an example of an ionogram, one for each station, for which the algorithm assisted Autoscala in correctly scaling the trace.

The Warsaw ionograms deserve a special mention. In fact these ionograms are tagged in terms of polarization and

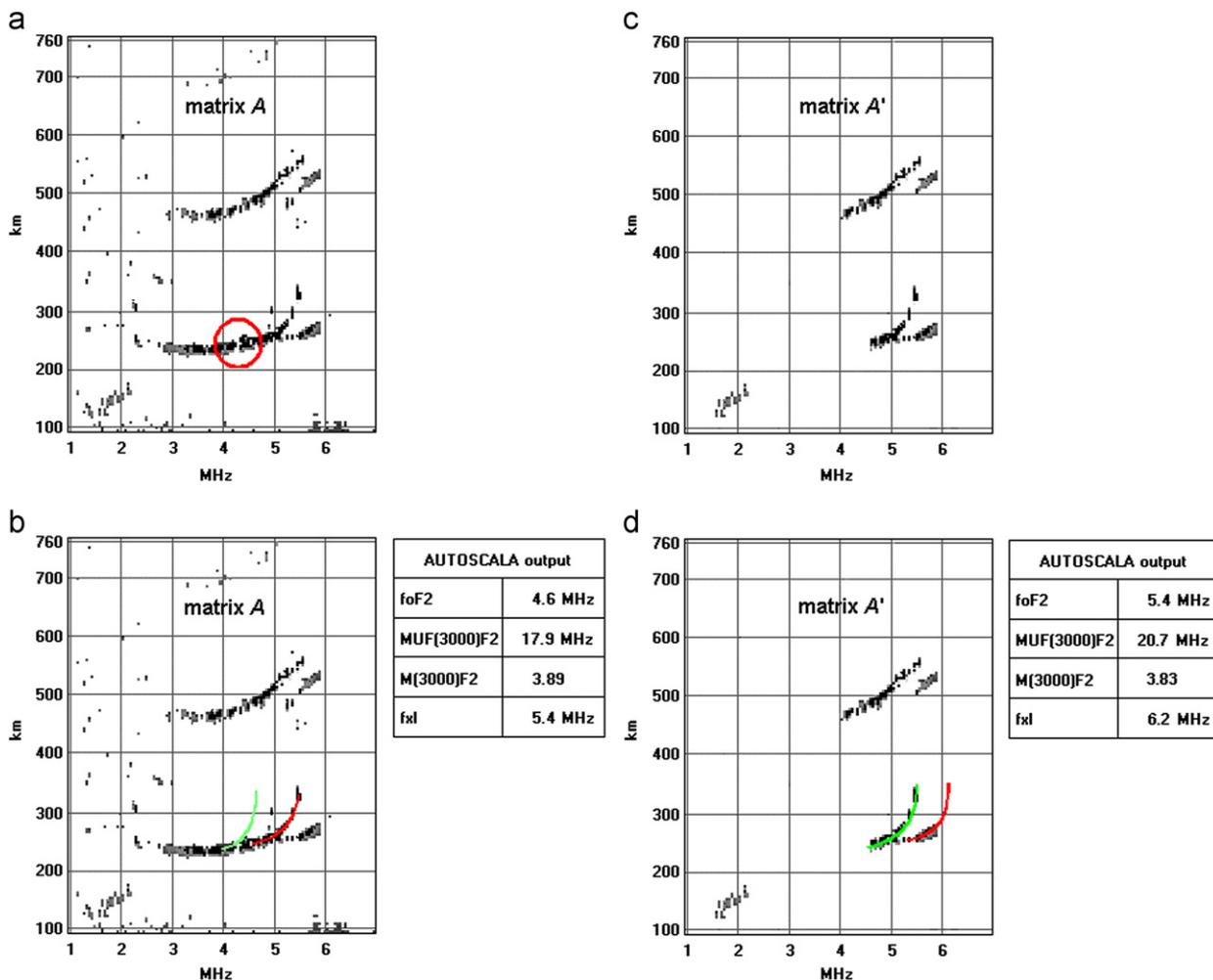


Fig. 7. (a) Ionogram recorded on 4 January 2009 at 08:15 UT by AIS-Parus installed at Moscow. Red open circle highlights part of ionogram trace, characterized by a horizontal or quasi-horizontal behaviour, that contributes to misleading Autoscala. (b) Autoscaling performed by F2 routine of Autoscala (in green and in red, ordinary and extraordinary traces, respectively, identified by software) which incorrectly identifies ordinary ray as extraordinary ray, considering ionogram points contained in red circle. (c) Ionogram loaded in matrix A' , in which parts of trace characterized by a horizontal or quasi-horizontal behaviour and by a behaviour with negative slope have been deleted, and which is subsequently processed by F2 routine. (d) Correct autoscaling performed by F2 routine of Autoscala on ionogram loaded in matrix A' . (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

consequently Autoscala would not identify the ordinary as the extraordinary ray, as described in the Introduction. These ionograms are also characterized by a high level of noise that may annoy the autoscaling process. Figs. 9 and 10 show two cases from Warsaw for which the method described in this paper turned out to be very useful in processing these kind of ionograms. Table 5 shows the results of the corresponding analysis.

We want to point out once more that the ionogram obtained after applying the method is processed only by the F2 routine, the most critical step of the whole algorithm, while the F1 and Es routines process the original ionogram.

6. The method in the light of existing algorithms

Previous sections have shown that, by including this method to highlight the cuspidal trace on the ionogram, Autoscala increased its performance significantly. This method may however represent an idea that can be considered also by other autoscaling systems. For those not relying on the polarization tagging of the

trace this method represents an aid in better recognizing the asymptotical part of the trace when this is not clearly defined. In general, independently of the polarization tagging of the trace, it is helpful for filtering out noise and for not being misled by multiple-hop Es layer echoes.

In order to perform an analysis of ionograms, Tsai and Berkey (2000) presented a procedure evolving from approaches used in image processing; in their work they pointed out the problems arising when the objects that are to be extracted from images are not well defined, mostly when weak interference occurs near the plasma frequency. The method described here can remove such an interference and overcome this issue. Moreover, this method does not depend on a local noise statistic threshold like the Ding et al. (2007) method does, and it is consequently more generally applicable.

ARTIST (see Fig. 6 of Pezzopane and Scotto (2007)) is often misled by multiple-hop Es layer echoes and it seems not to be able to differentiate the echo amplitudes belonging to the second reflection of the Es layer from the ones belonging to the centre of the F trace, defined by Reinisch and Huang (1983) as the frequency/range domain where the change of virtual height with

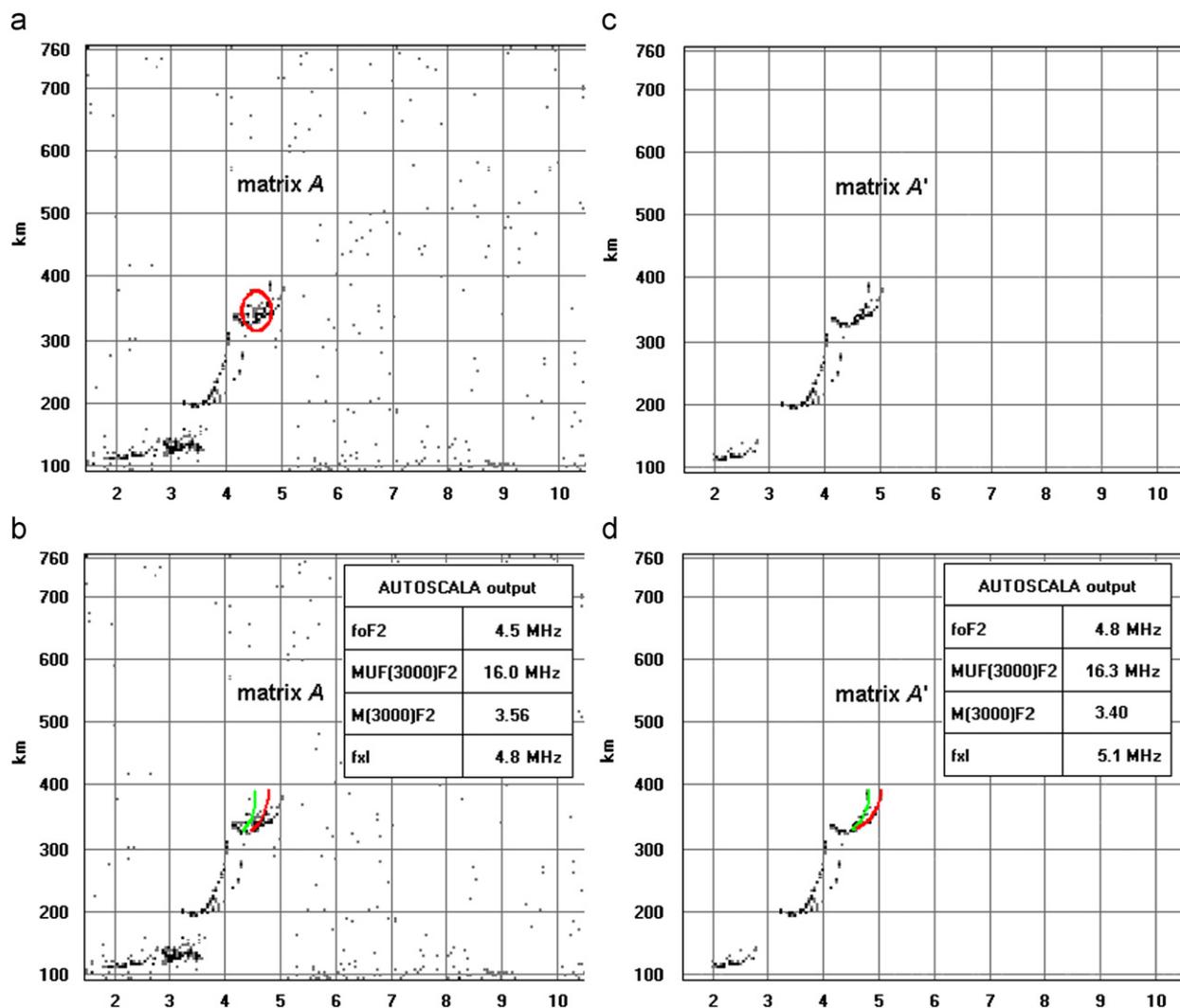


Fig. 8. (a) Ionogram recorded on 11 June 2008 at 14:45 UT by AIS-INGV installed at Tucumán. Red open circle highlights part of ionogram trace, characterized by a horizontal or quasi-horizontal behaviour, that contributes to misleading Autoscala. (b) Autoscaling performed by F2 routine of Autoscala (in green and in red, ordinary and extraordinary traces, respectively, identified by software) which incorrectly identifies ordinary ray as extraordinary ray, considering ionogram points contained in red circle. (c) Ionogram loaded in matrix A', in which parts of trace characterized by a horizontal or quasi-horizontal behaviour and by a behaviour with negative slope have been deleted, and which is subsequently processed by F2 routine. (d) Correct autoscaling performed by F2 routine of Autoscala on ionogram loaded in matrix A'. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

frequency is small and the echo amplitudes are strong. Complexity in identifying the F layer due to the presence of multiple-hop Es layers is discussed also by Tsai and Berkey (2000), Igi et al.

(1993), and Fox and Blundell (1989). As shown in Fig. 5 the method described here is helpful in assisting with this kind of ionogram signatures.

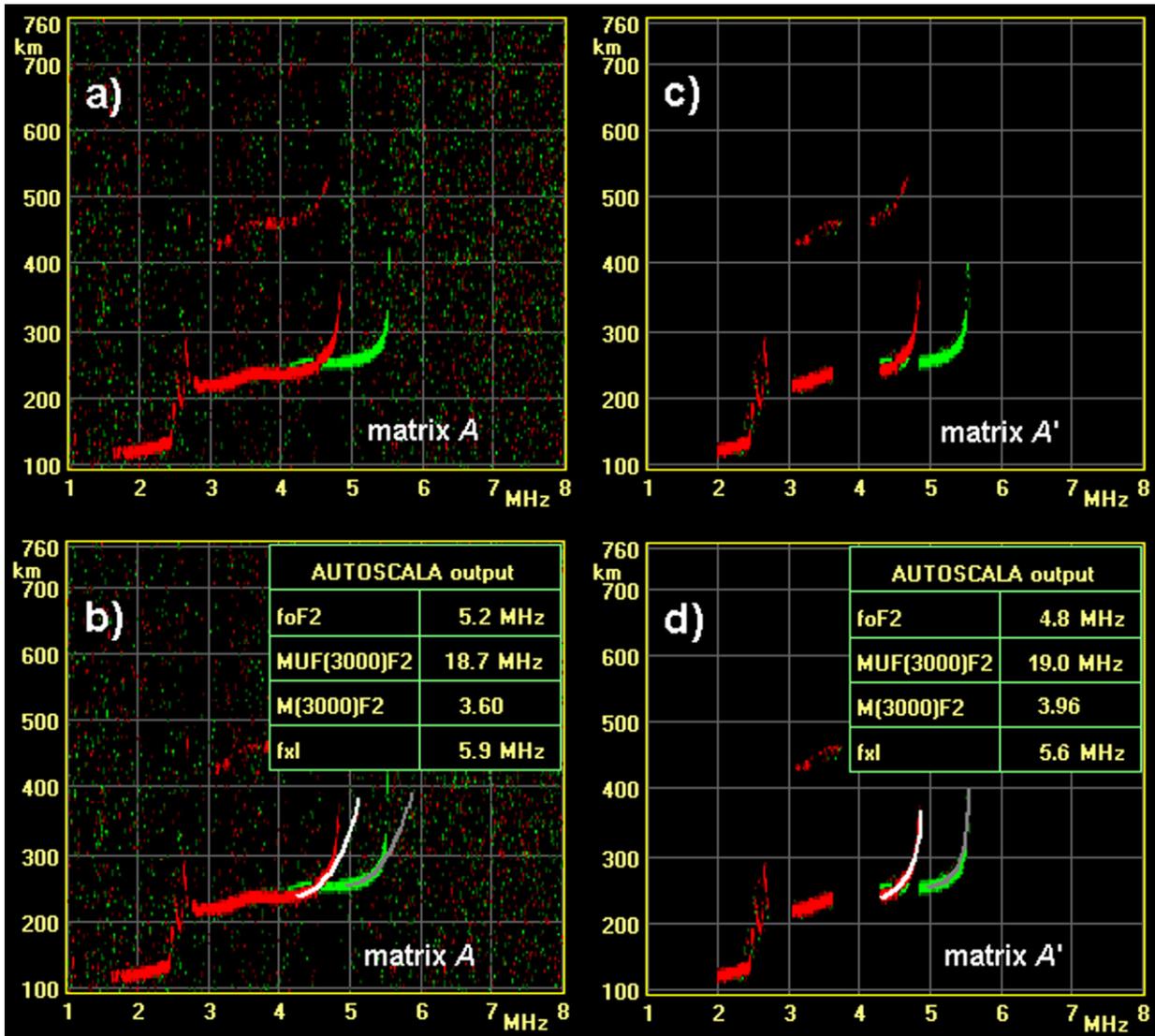


Fig. 9. (a) Ionogram recorded on 3 February 2009 at 11:00 UT by VISRC2 installed at Warsaw. (b) Autoscaling performed by F2 routine of Autoscala (in white and in grey ordinary and extraordinary traces, respectively, identified by software) which overestimates foF2 value considering noise points as belonging to ordinary ray. (c) Ionogram loaded in matrix A', completely cleaned by method described in paper, and which is subsequently processed by F2 routine of Autoscala. (d) Correct autoscaling performed by F2 routine of Autoscala on ionogram loaded in matrix A'.

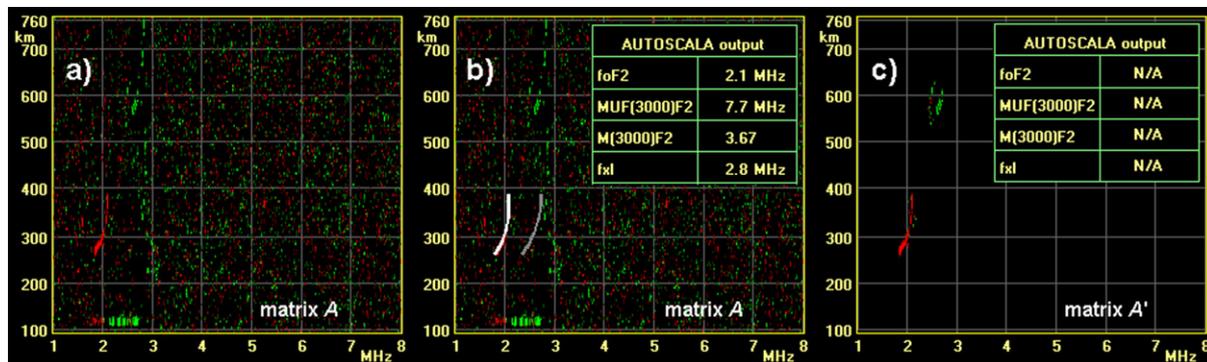


Fig. 10. (a) Ionogram recorded on 22 January 2009 at 17:00 UT by VISRC2 installed at Warsaw and characterized by a wrong polarization tagging of extraordinary trace. (b) Autoscaling performed by F2 routine of Autoscala (in white and in grey ordinary and extraordinary traces, respectively, identified by software) which incorrectly considers extraordinary ray as ordinary one. (c) Ionogram loaded in matrix A', completely cleaned by method described in paper, and which is subsequently processed by F2 routine of Autoscala that considers information of ionogram loaded in matrix A' insufficient to process it.

Table 5

Performance of F2 layer identification routine before and after applying method for highlighting F2 trace on ionograms recorded at Warsaw ionospheric station.

	Correctly scaled	Incorrectly scaled	Not scaled
Before applying the method	2889	76	
After applying the method	2956	3	6

7. Summary

This paper describes a method for redressing a problem affecting Autoscala which occurs when the ordinary ray of the F2 ionogram trace is more defined than the extraordinary ray, a feature visible mostly on daytime soundings, and tests performed showed that the application of this method improves Autoscala's reliability. Sections 4 and 5 have, however, highlighted the usefulness of this method in assisting autoscaling systems to not be misled by multiple-hop Es echoes, and to filter out noise, with consequently a better highlighting of the ionogram trace. In addition, it may be a valid algorithm for other approaches that are sometime affected by multiple-hop Es echoes and by interference signatures.

A routine containing the algorithm was added to the new version of Autoscala running on the ionograms recorded by the AIS-INGV ionosondes installed at Rome, Gibilmanna, and Tucumán stations, whose data is visible through the site <http://www.eswua.ingv.it/> (Romano et al., 2008). The same version is also running on ionograms recorded at Moscow and Warsaw, whose data is visible through the sites <http://ionos.ingv.it/Moscow/latest.html> and <http://rwc.cbk.waw.pl/iono/autoiono/index.php> respectively.

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